The Mechanics of LANL Foam Pads

Scott G. Bardenhagen, T-14; Brian M. Patterson, MST-7; Carl M. Cady, MST-8; Mathew W. Lewis, WT-1; Dana M. Dattelbaum, DE-9

Cellular solids are ubiquitous in nature (e.g., wood, bone), and have been found increasingly valuable in meeting the material demands of an expanding suite of specialized engineering applications such as energy absorption and packaging (e.g., honeycombs, foams). These materials have unique characteristics relative to more common structural materials, including complex, irregular structure at the cellular scale, high strength to weight ratios, and routine operation over large deformation ranges. Recent research on polymeric foams is advancing modeling, simulation, and analysis capabilities applicable to Los Alamos National Laboratory (LANL) weapon system components in particular, and cellular solids more generally.

The character of foam material response is typically assessed via compression experiments on sufficient quantities of foam that the underlying foam cellular structure is largely unimportant.

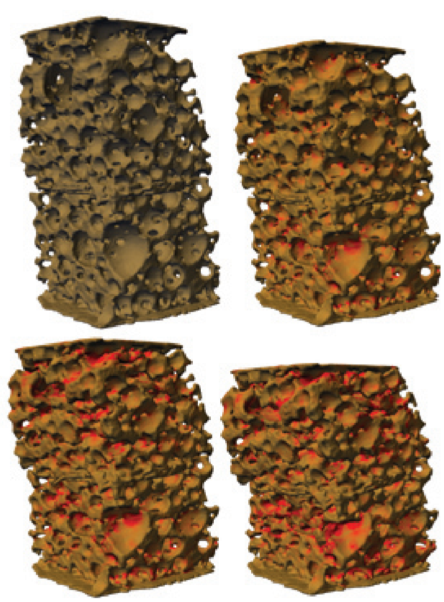

Fig. 1.
Foam structure as measured using microtomography (top left), and simulated compressed states, for a small column of foam.

These "bulk" measurements provide stress/strain curves that are useful in identifying common foam characteristics and categorizing response regimes. Examples may be seen in Fig. 2; S-shaped curves are typical of many types of foam. These data may also be used to calibrate engineering continuum models for bulk material response.

Bulk response data and models, while useful for many engineering tasks, are inherently inadequate for predicting the distributions and variability in material response evident in small foam specimens, or even cell-by-cell. Quantification of uncertainty in engineering systems requires as fundamental input material property variability. This is especially important in understanding the nature of damage and failure, which is typically controlled by the distribution of extreme events. The ultimate goals of this research on LANL foams are to characterize the distribution of states within a specimen, as well as the range of effective material property variability possible as the specimen size approaches the cell size.

Recent developments in particle-in-cell (PIC) methods indicate that these numerical techniques are suitable for precisely this class of problem [1]. Using foam structures determined using x-ray microtomography (similar to a CAT scan), quasi-static compression was simulated with results in agreement with experimental data in the literature. It was predicted that the full foam sample is an auxetic material at modest compressions, and that it becomes progressively more difficult to remove porosity, resulting in residual porosity even in "fully densified” foam. This work was featured as an example of the contribution of numerical simulation and visualization in stockpile stewardship in the *Wall Street Journal* [2].

A similar study is now targeting LANL foam pads. This study is providing new estimates of foam “parent” material properties (the material properties of the individual foam struts). Because these are blown foams (manufactured using a curing process that evolves gas), it is impossible to manufacture the parent material in bulk for testing. One recourse is extrapolation from material testing results on ever more-dense foams, created by alterations in manufacturing that invariably affect parent material properties to an unknown extent. Another is extraction of structural elements (e.g., struts) for testing, which also has unresolved complications, in this case due to both the scale and geometry of the extracted parts. Numerical simulation provides an equally, if not more viable, alternative.

An in-house x-ray microtomography facility has recently been acquired and used to characterize LANL foam pads. These data and some of the first simulation results using these data may be seen in Fig. 1, where a column of foam in various states of compression is depicted.

Bulk stress strain curves for several foam pad samples are depicted in Fig. 2. The experimental data are colored by test lot, and cover a range of relative densities from 32–37%. Specimen variability within a test lot is fairly small. However, between lots it is larger, as illustrated by the highest relative density test lot stress strain curves (light blue) lying between lower relative density lots (purple, dark blue).

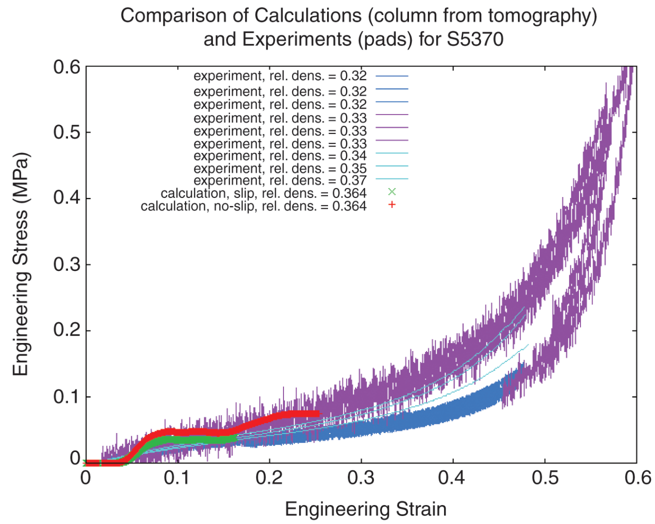

Fig. 2.
Bulk stress-strain curves for LANL foam pads (blue, purple) and simulation results for the foam column (red, green).

Although the specimen in Fig. 1 is much smaller than the foam pad samples that generated the data in Fig. 2, its average response is expected to be similar. Simulation results for two different boundary conditions are depicted (red, green) and both are found to lie within the scatter of the experimental results. This fit required a substantial revision of the parent material properties from a previous estimate [3]. The shear modulus was reduced by a factor of three, and the bulk modulus increased by a factor of four. Future work includes determining the distributions of material states and effective material properties for input into uncertainty analyses.

For more information contact Scott Bardenhagen at bard@lanl.gov.

[1] A.D. Brydon, et al., *J. Mech. and Phy. Solids* **53**, pp. 2638–60 (2005).
[2] “Cold War Echo; U.S. Weighs Whether to Build Some New Nuclear Warheads,” *The Wall Street Journal*, December 14, 2005.
[3] M.W. Schraad and F.L. Harlow, *Intl. J. Mech. Sci.* **48**, pp. 85–106 (2006).

Funding Acknowledgements
NNSA’s Advanced Simulation and Computing (ASC), Materials and Physics Program; and Campaign 2, Dynamic Materials Properties.